Marine Pollution Bulletin 56 (2008) 1538–1544

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Interrupting a multi-species bioinvasion vector: The efficacy of in-water cleaning for removing biofouling on obsolete vessels

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ARTICLE INFO

Keywords:
Biofouling
Ships
Nonindigenous species
Transfer mechanism
Vector management
In-water cleaning

ABSTRACT

Vector management is the primary method for reducing and preventing nonindigenous species (NIS) invasions and their ecological and economic consequences. This study was the first to examine the efficacy of in-water scrubbing using a submersible cleaning and maintenance platform (SCAMP) to prevent invertebrate species transfers from a heavily fouled obsolete vessel. Initially, prior to treatment, 37 species were recorded in a biofouling matrix that reached 30 cm depth in some locations. The bryozoan *Conopeum chesapeakensis,* and bivalves *Mytilopsis leucophaeata* and *Ischadium recurvum*, were dominant sessile species that created structure, supporting mobile biota that included crabs and the associated parasitic barnacle *Loxothylacus panopae*. Scrubbing had the effect of significantly reducing organism extent and the number of species per sample, but a substantial and diverse (30 species) residual fouling community remained across the entire vessel. Further assessments of management options are needed to prevent potentially damaging NIS transfers. Additional measures taken within an integrated vector management (IVM) strategy may further improve invasion prevention measures.

1. Introduction

Preventing nonindigenous species (NIS) introductions through effective vector management is the leading tool available to agencies and managers concerned with impacts of invasive species (Ruiz and Carlton, 2003). Although rapid response, control, containment and eradication of species are desirable and sometimes unavoidable, these reactive measures can be labor intensive, time consuming and expensive, with limited opportunity for success unless timely detection, authorization, resources and expertise are put in place (Anderson, 2005). Moreover, the success of reactive measures is often contingent upon successfully preventing new incursions of NIS propagules during and after the eradication effort, highlighting the primacy of vector management.

For marine systems, shipping is a dominant transfer mechanism (vector) responsible for species transfers (Ruiz et al., 2000) and operates to transfer diverse biotic communities associated with ballast water and hulls (including a diverse array of surfaces). An effective interruption or management of the vector phase for these transfer mechanisms, therefore, will work to prevent a suite of species incursions. A recent and widespread vector management effort currently underway in marine systems is open-ocean ballast water exchange. By discharging coastal water (and associated organisms) from ballast tanks during ballast exchange and replacing it with oceanic water, the risk of species transfers from this vector can be reduced (e.g., IMO, 1991; Wonham et al., 2001; Minton et al., 2005; McCollin et al., 2007). Similarly, antifouling paints and hull husbandry reduce vessel biofouling transfers (Callow and Callow, 2002; Coutts and Taylor, 2004).

A subset of vessels, however, is not subjected to these hull maintenance practices and may pose a significant threat of species introductions (Foster and Willan, 1979; Brock et al., 1999; DeFelice, 1999; Godwin and Eldredge, 2001; Lewis et al., 2006). These vessels include inactive ships and barges, floating docks, oil platforms and other laid-up or unusual vessels. These vessels are dwarfed in number by active commercial and military vessels around the world, but account for a far higher risk of species introductions on a per-ship basis. Factors such as long lay-up times, slow speeds and lengthy durations at recipient ports, combined with a lack of hull maintenance, ensure that very dense and extensive assemblages of biofouling organisms get relocated and provided with an opportunity to establish in new areas (DeFelice, 1999; Davidson et al., 2008).

There is growing concern regarding these high-risk biofouling vectors (Godwin, 2005) and options for vector management are needed. Several strategies and tools exist and range from rudimentary and inexpensive to relatively complex and costly. They include beaching to cause desiccation, in-water cleaning, smothering with plastic, chlorine treatment (Coutts and Forrest, 2007), altering

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doi:10.1016/j.marpolbul.2008.05.024

salinity regimes (Brock et al., 1999), temperature or heat treatment (Wotton et al., 2004), and dry docking. The efficacy of these different approaches varies with differing conditions that are not well understood, however, and more studies are required to determine the merits and limitations of these strategies.

In this study, we used a stratified sampling protocol to measure the effectiveness of in-water scrubbing for reducing the number of organisms on the submerged surfaces of an obsolete vessel prior to its final voyage to a ship dismantling facility. The vessel ORION, one of the ghost fleet ships retained by the US Maritime Administration, was being transported to a ship breaking facility from the James River Reserve Fleet (JRRF) at Fort Eustace, Virginia, USA. After laying stationary at the JRRF for 13 years, allowing for substantial biofouling accumulation, we assessed biofouling extent, species richness and assemblage organization before and after in-water scrubbing at a variety of underwater vessel (hull) locations to determine the efficacy of in-water cleaning as a vector interruption tool. This was the first such analysis of vector management for obsolete vessels in the US.

2. Methods

2.1. Underwater sampling

Vessel sampling was conducted at the JRRF, which is situated approximately 39 kilometers upstream of where the James River reaches the Chesapeake Bay. There are several rows of vessels tied side-by-side at the JRRF, and the ORION was situated centrally in a row of 14 ships. The vessel was sampled on two occasions (27th and 30th of June, 2006) at this location, before and after in-water cleaning. Water temperature varied between 27 °C and 28.4 °C and salinity varied between 4 and 10.4 ppt during surveys. In-water cleaning was conducted by technicians of Seaward Marine Services Inc., using a submersible cleaning and maintenance platform (SCAMP) on the hull and hand-held brushes on vessel appendages. A SCAMP is a self-propelled vehicle, usually accompanied by a diver, of approximately 1.8 m diameter with multiple rotating/oscillating circular brushes that scrub surfaces as they move across vessel hulls. The brushes used for cleaning the ORION had bristles of polypropylene with steel inserts and also just polypropylene alone. The hand-held brushes were used on the rudder, propeller, stern tube, and struts (vessel appendages) because the SCAMP cannot access heterogeneous, confined or concave surfaces.

Pre- and post-scrubbing surveys were conducted *in situ* using divers connected by real-time audio and visual communications to a surface support team. Divers sampled the vessel by collecting photographic images and biological samples in a sampling scheme stratified by vessel location. The four levels of stratification included hull sampling at three depths (bottom, mid depth and just below the waterline) and vessel appendages. Images were collected using an underwater camera that captured photo-quadrats of 15 cm × 15 cm area (225 cm^2). A total of 64 pre-scrubbing and 58 post-scrubbing images were collected and used in analyses. Replicate biological sample collections were made using the same stratification scheme, consisting of 32 biological samples collected for each pre- and post- cleaning survey (64 in total). Collections were made by removing all macro-organisms from areas measuring 231 cm^2 (six square inches) and placing them into individually labeled re-sealable (zipped) bags. Preliminary sorting of biological samples was done in the field, as soon as possible after collection (less than 90 min), to determine whether organisms were alive or dead. Our goal was to assess quickly whether living specimens of each species were present, as this cannot be easily or reliably determined from preserved samples. This was accomplished by coarsely sorting through material in the samples and vouchering specimens of each morpho-species that were alive. Detailed note taking, labeling and sample preservation were also carried out on board the research vessel. Samples were preserved in 95% ethanol and returned to the laboratory, where detailed processing took place to estimate the number and identity of species in each replicate sample. Specimens were sent to expert taxonomists for identification and verification and organisms were identified to the lowest possible taxonomic level.

2.2. Data analyses

Photo-quadrats were analyzed using the point count method to determine percentage cover of different fouling groups by superimposing a grid of 100 random dots over each photo-quadrat. Fouling groups consisted of eight coarse categories that were readily identifiable from the images: barnacles, mussels, oysters, encrusting species, filamentous species (mainly hydroids and erect bryozoans), mobile crustaceans, organism scars and hull surface. A data matrix consisting of percentages of each of the eight fouling categories per sample was used for assessing biofouling extent. The biological samples data, a presence/absence matrix of species per sample, was used to examine variation in biofouling species richness and assemblage composition among samples.

The two data matrices were used separately for univariate analyses, multivariate analyses and graphical presentation. A two-factor ANOVA was used to test for differences in species richness and biofouling percent cover using scrub (2 levels: before and after) and hull location (4 levels: appendages, bottom, mid depth and waterline) as factors. Ordinations were carried out using the multidimensional scaling (MDS) technique in PRIMER (PRIMER-E Ltd., Plymouth, UK), which produces a plot revealing sample similarity from Bray-Curtis similarity measures: points close together in the plot represent samples that are compositionally similar while those far apart are dissimilar. The analysis of similarities (ANOSIM) test was used to test for significant differences between factors. The test statistic (R) is usually a value between zero and one, with values close to one revealing that groups of samples are clearly distinguishable and dissimilar in terms of species composition whereas values close to zero mean that groups of samples are similar in composition (Clarke and Gorley, 2001).

3. Results

3.1. Biofouling samples: species richness

There were 39 distinct taxa (species and species groups, the latter including unique species that were not identifiable to species level as well as invertebrate juvenile stages, damaged specimens, fish eggs and larvae) recorded from the 64 biological samples collected from both surveys (Table 1). These 39 unique taxa are referred to as species from this point forward. Twenty-eight species were recorded in both pre- and post-treatment surveys, 9 were recorded from the pre-treatment survey only, and two were encountered during the post-treatment survey only (Table 1). Four species, *Conopeum chesapeakensis* (bryozoan), *Balanus improvisus* (barnacle), *Neanthes succinea* (polychaete) and *Apicorophium lacustre* (amphipod), were recorded in 100% of pre-scrub samples. Live specimens of all abundant or common species (occurring in >50% of samples) were collected. Although complete specimens of other rarer species were observed, no determination of live versus dead was possible for these species because they were not encountered alive during preliminary sorting. Of the 26 species that were recorded alive during pre-scrub surveys, only three were not recorded alive during post-scrub sampling. Two of these three species were not recorded in post-scrub samples at all, while *Polydora* sp. was only recorded (post-scrub) after sample preservation.

Table 1
The 39 species recorded on the hull of the obsolete vessel ORION. Species status is indicated as L = live, P = present and A = absent based on the status of organisms during ship-side and laboratory sampling

Taxonomic group	Species (or lowest taxonomic level possible	Status	
		Pre	Post
Algae	*Enteromorpha* sp.	L	L
	Chlorophyta A	P	A
	Rhodophyta A	L	L
Hydroids	*Garveia franciscana*	L	L
	Campanulinid sp.	L	L
	Unidentified hydroid sp.	P	A
Bryozoans	*Conopeum chesapeakensis*	L	L
	Bowerbankia sp.	L	L
	Victorella pavida	L	L
Crustaceans	*Balanus improvisus*	L	L
	Barnacle cyprid	L	A
	Loxothylacus panopaei	p	A
	Apicorophium lacustre	L	L
	Stenopluestes sp.	L	L
	Gammarus cf tigrinus	P	A
	Melita planaterga	L	L
	Synidotea laticauda	L	L
	Melita sp.	L	L
	Eurypanopeus depressus	L	L
	Rhithropanopeus harrisii	L	L
	Callinectes sapidus	L	L
	Unidentified decapod	L	A
	Unidentified crab zoea	A	P
	Calanoid copepod sp.	A	L
	Harpacticoid copepod sp.	L	L
Molluscs	*Mytilopsis leucophaeata*	L	L
	Ischadium recurvum	L	L
	Crassostrea virginica	L	L
	Unidentified gastropod	P	A
Annelids	*Neanthes succinea*	L	L
	Polydora sp.	L	P
	polychaete A	P	A
	polychaete B	P	A
	polychaete C	P	A
Platyhleminthes	*Stylochus ellipticus*	L	L
	Euplana sp.	L	L
Nematodes	Nematode A	P	P
Fish	Unidentified fish larva	P	P
	Fish eggs	P	P

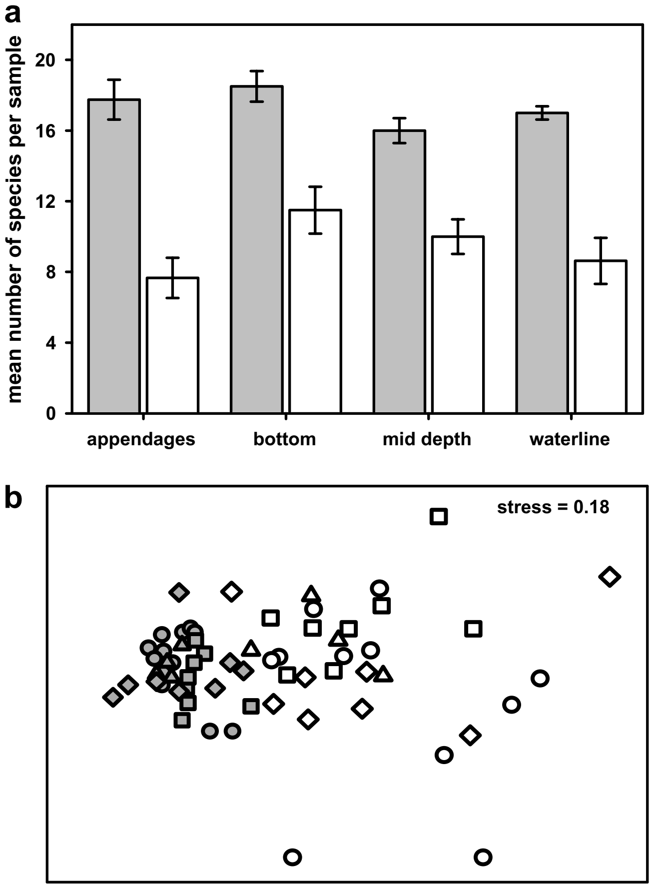

Fig. 1. (a) Mean number of species per sample in pre- and post- scrub surveys. The mean species density per sample (and standard error) are plotted for four hull locations for pre-scrub (grey bars) and post-scrub (white bars) sampling. (b) MDS plot of assemblage organization based on presence/absence of species in biological sample collections. White and grey symbols represent pre- and post-scrub sampling, respectively. Different hull locations are shown as circles (vessel appendages), triangles (bottom depth), squares (mid depth), and diamonds (waterline).

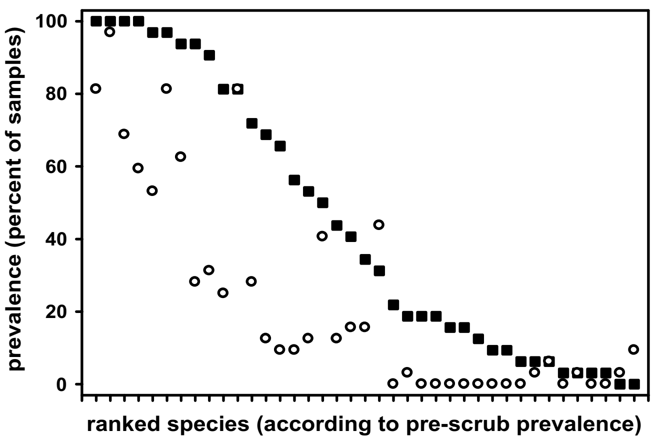

Fig. 2. Species prevalence in samples for pre- and post-scrub surveys. Species are ranked along the *x*-axis from highest to lowest prevalence in pre-scrub samples. Percent occurrence across samples is represented by black squares (pre-scrub sampling) and white circles (post-scrub sampling).

There were significantly fewer species per sample after the vessel had been scrubbed (ANOVA, d.f. = 1, $F = 85.62$, $p < 0.001$), and this was consistent across the four different hull locations (Fig. 1a). This pattern also emerged from the MDS plot of species presence/absence data (Fig. 1b) whereby no significant differences in assemblage composition were evident between hull locations, but there was a difference between pre- and post-cleaning (ANOSIM, $R = 0.473$, $p < 0.01$). The greatest reduction in species was observed for the running gear surfaces where the mean number of species per sample dropped from 17.75 to 7.6. The reduction in species richness per sample for running gear surfaces was not significantly different from hull surfaces, however. For the entire vessel, the number of species recorded decreased from 37 to 30 between initial and final surveys.

The prevalence of each species across samples between pre- and post-scrubbing surveys was highly variable (Fig. 2), ranging between 100% 'removal' to no change in prevalence (0%), as well as three species found in higher numbers of samples after scrubbing compared to before. Two of the species were not recorded in pre-scrub samples (therefore increased from zero occurrences). The third, *Crassostrea virginica* (oyster), was recorded in 31.2% of

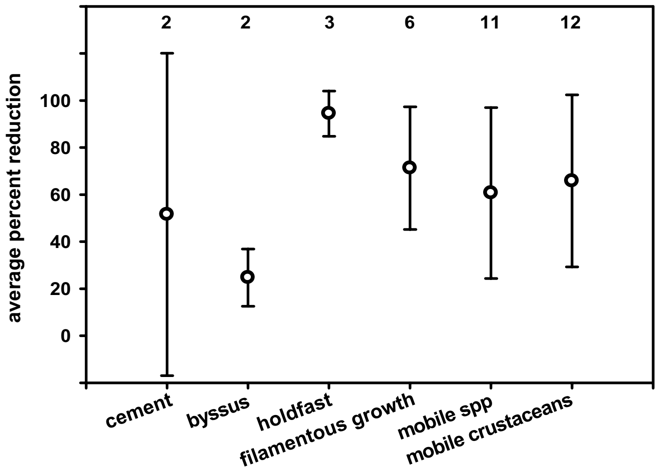

Fig. 3. Mean percent reduction of organisms grouped by attachment type. The mean reduction (and standard deviation) in species prevalence between pre- and post-scrub sampling is presented. Numbers above each category show the *n* for that category. Cement-, byssus- and holdfast-attached species include barnacles, mussels and algae, respectively. Filamentous species include hydroids and erect bryozoans. Mobile species were divided between crustacean and non-crustacean taxa. Three species that increased in sample prevalence were not included in this figure.

pre-scrub samples and 43.7% of post-scrub samples. There were eight species during the pre-treatment survey that occurred in 30 or more samples of the 32 taken. With the exception of the hydroid *Garveia franciscana*, each of these species occurred in more than 50% of the samples collected during the post-treatment survey. The impact of scrubbing appeared most effective for removing algae (Fig. 3), with an average 96% reduction (s.d. 9.6%) in occurrence across samples. Species that use byssus for attachment were reduced by an average 24.7% (s.d. 12.1%) of samples. Cement-attached species varied considerably, with one species increasing in sample occurrence (*C. virginica* above) but two others reducing by 100% and 3.1%. There was also substantial variation among unattached mobile species (Fig. 3).

3.2. Photo analysis: biofouling extent

Photo-quadrat data also revealed no differences in assemblage organization between hull locations for each survey, but there was a significant difference between pre- and post-scrub samples (ANOSIM, $R = 0.504$, $p < 0.01$). A substantial and significant increase in exposed hull surface (bare space) was the most striking feature of the photo-quadrat comparisons between pre- and post- scrub surveys (ANOVA, $F = 159$, $p < 0.001$). The mean percent area of exposed hull surface increased from 10.9% (S.E. = 2.0) per sample prior to scrubbing to 62.7% (S.E. = 3.7) after scrubbing. A large increase in bare space (a combination of 'hull surface' and 'organism scars' categories) was consistent across all depths of the hull and on the surfaces of the vessel's running gear (Fig. 4). This increase in bare space coincided clearly with reductions in encrusting species, barnacles, and filamentous biofouling. These biofouling groups were not eliminated, however, and mean percent cover of encrusting species across all post-scrub samples was 21.8%.

4. Discussion

4.1. Biofouling and in-water cleaning

The high levels of biofouling with little variation among hull locations found on the ORION represent common features of stationary vessels that receive little or no hull husbandry (Brock et al., 1999; DeFelice, 1999; Coutts, 2002; Minchin and Gollasch, 2003; Davidson et al., 2008). Such vessels tend to have extensive biofouling assemblages in both hull and non-hull areas that exceed niche area fouling of most operational ships. This elevated level of biofouling is expected to increase the risk of transfers and invasions on a per-ship basis because of higher numbers of propagules per inoculation (Grevstad, 1999; Drake and Lodge, 2006). Several species recorded in high numbers from the ORION, including the bivalves *Mytilopsis leucophaeata* and *Ischadium recurvum*, have had negative impacts in their non-native ranges (Fofonoff et al., 2003; Laine et al., 2006; Verween et al., 2007) and represent invasion threats to regions that receive arrivals of obsolete vessels from the JRRF.

Interestingly, the crab parasite *Loxothylacus panopaei,* which parasitizes several crab species including *Rhithropanopeus harrisii* (Alvarez et al., 1995), was also recorded in 18% of pre-scrub samples. *R. harrisii* itself is a very successful invader with established non-native populations on the coasts of 21 different countries in Europe, North and Central America, Asia and Africa (Roche and Torchin, 2007). The additional risk of spreading *L. panopaei* associated with *R. harrisii* could have serious consequences for recipient regions. Parasites cause serious ecological and economic impacts and their transfer poses a particular threat to uninfected regions, particularly for fisheries and aquaculture (Torchin et al., 2002). The risk of their transfer via biofouling on vessels may be underappreciated generally and has particular relevance for heavily fouled vessels from Chesapeake Bay. Two other notorious parasites, the oyster protozoan parasites *Haplosporidium nelsoni* and *Perkinsus marinus* (MSX and Dermo, respectively) also occur in Chesapeake Bay (Torchin et al., 2002). *H. nelsoni* (MSX) has been responsible for extremely high mortalities of native oysters in Chesapeake Bay and is of Asian origin (Ruiz and Carlton, 2003). It is not known to occur in the Gulf of Mexico, which is a frequent destination for obsolete vessels, because several ship dismantling operations are located on the Gulf Coast. We did not analyze bivalve tissue to determine the presence or absence of MSX or other parasites in this study, but such examinations would clearly be required for an in-depth risk analysis.

The notable result of in-water scrubbing was that there was a significant reduction in organism cover on vessel surfaces (mainly evidenced from image analysis) but persistence of several species across samples (mainly evidenced from the biological sample collections). This highlights the problematic nature of managing such extensive biofouling vectors; even when propagule delivery is reduced, further risk analysis is required to determine if the reduction translated into an effective decline in the threat of an invasion. The SCAMP method of in-water scrubbing can be considered favorable to no pre-departure management effort, however, even though we recorded viable specimens from a majority of species on the ORION after scrubbing. Moreover, comparisons between this study and another of two similar vessels (Davidson et al., 2008), suggest that in-water cleaning is more effective at creating bare space and removing organisms than transit alone.

Holm et al. (2003) have demonstrated that several factors, including brush position, brush angle, rotation rate, bristle density and bristle stiffness, interact in a complex manner to determine the forces required to remove organisms from submerged surfaces. They also highlighted an important consideration for in-water cleaning of commercial vessels; the forces applied by brushes are generally required to remove organisms with minimal damage or removal of paints. Preserving the life span of antifouling paints is not important for obsolete vessels, so determining the best combination of brush and bristle parameters for organism removal can focus on the inter- and intra-specific variation in adhesion strength among organisms (Kavanagh et al., 2001). This is a useful consideration for decommissioned vessels because standard tools used for commercial vessels, such as the SCAMP in this instance, could

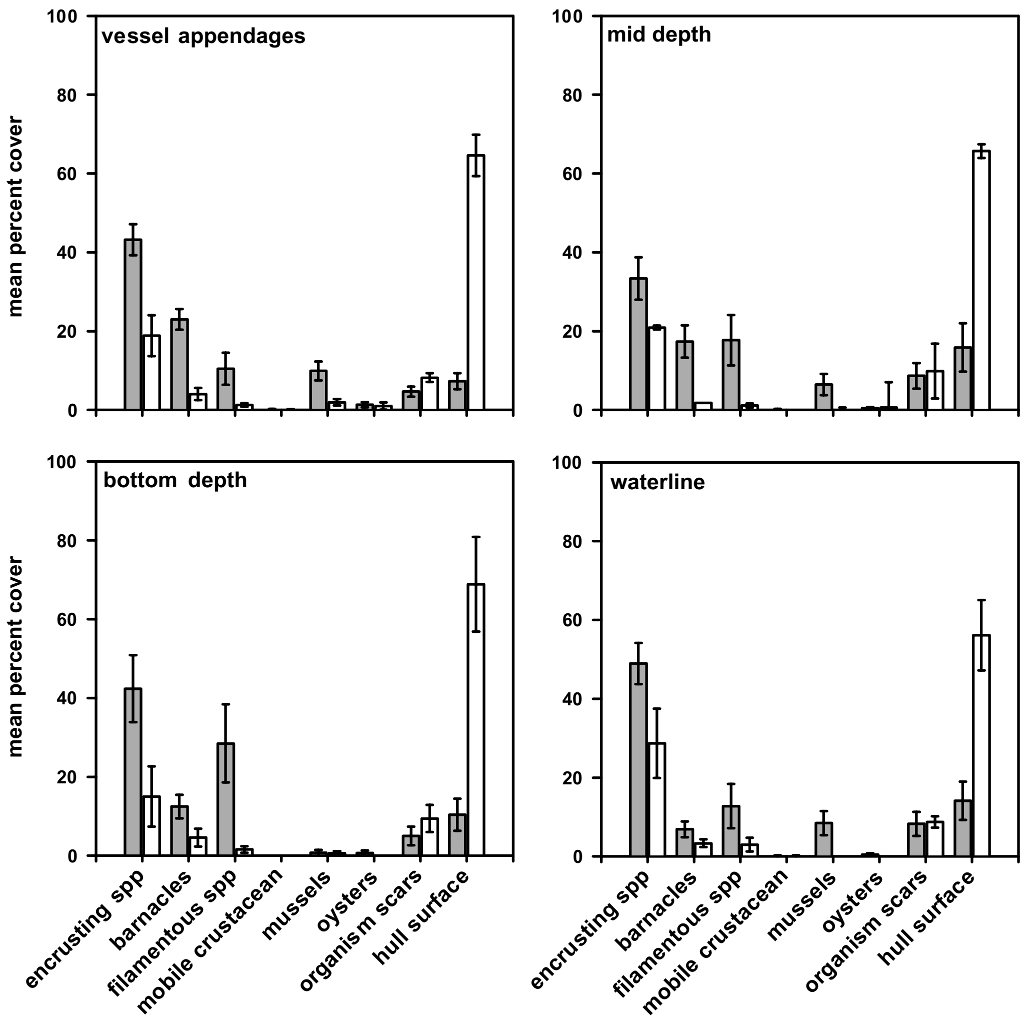

Fig. 4. Differences in biofouling percent cover between pre- and post-scrub surveys. The mean (and standard error) percent cover of seven categories of biofouling and bare hull estimated from photo-quadrats is plotted (eight categories in total). Grey and white bars represent pre- and post-scrub data, respectively, for four hull locations (vessel appendages, waterline, mid depth and bottom depth).

be modified for circumstances unhindered by concerns regarding paint preservation (although issues of pollution and hull integrity remain). Stronger forces from different brush and bristle combinations than those applied in this case study, therefore, may prove more thorough at removing biofouling on obsolete ships.

There are several critical issues that remain unresolved and deserve further consideration to ensure a sound assessment of invasion risk and vector management of obsolete ships (and other high-risk ships) for future vessel transfers. Our analysis was restricted to one vessel at one location and season, and therefore results should not be considered broadly representative of biofouling invasion risks from obsolete ships. There are strong reasons to expect significant variation by location and season, as the biological communities (species composition) will vary accordingly. Any management decisions would clearly benefit from analysis of the three US Reserve Fleet sites (on the East, Gulf and West Coasts) across different seasons, and some level of replication, to develop a robust understanding of treatment effects. An optimal strategy would also include evaluations of the effects of biogeographical differences between source and destination ports including the physiological tolerance of those species present at reserve fleet locations to conditions present at destination ports (for ship-breaking) and *en-route*. Voyage routes are an important consideration, since most ship breaking in the US occurs on the Gulf Coast and in Chesapeake Bay itself, although some JRRF ships have been transferred internationally, including four vessels currently tied at dock in NE England (Minchin, 2006).

The risk of invasion from residual biofouling communities (after in-water cleaning and after transit) has not been adequately addressed for obsolete vessels of the Reserve Fleet. It is clear that in-water cleaning reduces organism numbers. It is also likely that cleaning followed by movement (towing) would cause a further reduction, but this has not yet been estimated and another study has shown how species richness can increase during transit (Davidson et al., 2008). Furthermore, current post-voyage ship dismantling practice involves vessels being dragged out of water iteratively, over a period of weeks, as the vessel is taken apart. This relatively long in-water residence time increases the probability of species successfully recruiting from the vessel to the port environment, although little else is known about the quantitative influence of duration on invasion potential. For this and other reasons, the State of Oregon has adopted a regulation that requires all potential ship dismantling be conducted on dry docks only (2007 Oregon Senate Bill 432).

Additionally, we did not assess the effect of in-water cleaning on release of bottom paints or other toxic materials (or the fate of removed organisms). Concerns over paint effectiveness and damage are moot for these vessels on their final voyages, but pollution concerns are valid and are being investigated (MARAD, pers. comm.). Many obsolete vessels are several decades old and studies of the nature and fate of removed material are necessary, particularly because there are regulatory considerations. There are US federal (Code of Federal Regulations 151.2035) and state regulations (e.g., California Assembly Bill No. 740) requiring containment of such material for dry docking and cleaning practices. Other countries, such as Australia, do not allow in-water cleaning of internationally plying vessels in Australia's waters (AQIS, 2007). As biofouling management emerges as a strategy (similar to ballast water management), ongoing evaluation of tools may lead to solutions that manage the invasion risk while preventing pollution at cleaning sites.

4.2. Biofouling vector management

The movements of obsolete or unusual stochastic vessels with high levels of biofouling are an issue for several agencies and the maritime shipping industry in the US and worldwide. Because the risks of invasion from vessel transfers of this nature are high, and certainly much higher than for regular in-service ships, management considerations are needed at international, national and regional levels (Ruiz and Carlton, 2003; Godwin, 2005). Indeed, in biofouling vector studies there has been a change of emphasis in terminology from 'hull fouling' to 'vessel biofouling'. This change has occurred for two reasons: (1) the need for precision and clarity when evaluating vectors and their subcomponents (Carlton and Ruiz, 2003); and (2) by the economic factors that ensure shippers maintain their hulls but not always the niche areas (e.g., running gear appendages) where well-developed biofouling assemblages tend to accumulate (Coutts and Taylor, 2004). Thus, hull fouling is not considered an accurate descriptor of commercial vessel biofouling because most hull surfaces can be free of fouling, while fouled (non-hull) niche areas do not appear to carry a financial penalty that would promote more regular cleaning. For this reason, the US Code of Federal regulations (33 CFR 151.2035) has added a regulatory incentive to the existing financial incentive to encourage shippers to ensure all submerged surfaces do not accumulate heavy fouling.

The success of vector management strategies can be measured by monitoring the number and rate of new invasions to an area after the management activity has come into force. This measure of success or failure is the ultimate measure of management efficacy (Ruiz and Carlton, 2003), but requires a longer-term commitment and effort. The other measure, undertaken in this study for macro-invertebrates, is to examine the effect of management on propagule delivery. Overall, in-water scrubbing caused a significant reduction in the extent (both percent cover of organisms and frequency of occurrence of species) of biofouling organisms on the hull of the ORION. Although this is likely to reduce the associated risk of invasions to some extent, the residual biofouling recorded in post-scrub sampling was extensive and diverse.

The extent to which invasion risk was reduced is unknown, therefore, and this remains a critical issue that will determine the ultimate success of this vector management technique. Testing different brush configurations, tailored for obsolete vessel hulls and their unusually high biofouling levels, would promote increased efficacy for reducing propagule delivery. To our knowledge, there has not been a synthetic review of different in-water cleaning methods and their performance under various conditions. Existing studies, including the present one, have examined hull cleaning on a case-by-case basis. Reviewing the efficacy of different methods with a view to developing more robust replicated testing may prove insightful for managing future risks. Furthermore, the combined effect of multiple treatments at different stages of the vector process (pre-departure × voyage × post-arrival) remains to be examined.

Pre-transfer approaches, such as in-water scrubbing, could be incorporated as part of an integrated vector management (IVM) strategy for obsolete vessels. IVM is a management framework that utilizes information from different vector stages to maximize vector interruptions (Carlton and Ruiz, 2003). Additional components in the obsolete vessel transfer process could include some hull husbandry during the preceding lay-up time, salinity or temperature treatments *en-route*, and/or post-transit management (e.g. docking, beaching or additional targeted scrubbing with suction/retention capability; Coutts and Forrest, 2007; Hopkins and Forrest, 2008) upon arrival at the destination port. These would combine to reduce propagule supply, which we would expect to reduce the invasion risk from obsolete ships. Until a better understanding of propagule supply and invasion risk (dose-response relationships; Lockwood et al., 2005) is achieved, this precautionary approach appears most suited to preventing biofouling-mediated invasions. The value of IVM as a biologically- and cost-effective management strategy may be substantial if damage and post-invasion costs from NIS can be prevented.

Acknowledgements

We are grateful to C. Junemann of MARAD and the staff at the James River Reserve Fleet for information and logistical support during this project. We also wish to thank Seaward Marine Services Inc. for their expertise and helpful involvement. Fieldwork, lab work and taxonomic assistance were provided by George Smith, Safra Altman, Shelley Sullivan, Amanda Gilborn, Patrick Baker, Lea-Anne Henry, and James Thomas. Thanks to R. Everett and L.S. Godwin for helpful discussion of some topics covered in this manuscript. This project was funded by the US Maritime Administration.

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